Chapter 16
Watershed Management

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The Watershed Management Approach

Watershed management represents a unique approach to managing natural resources in that it gives particular attention to soil and water resources in a drainage basin context. Historically, this approach has been used primarily to protect and maintain municipal water sources, but more recently it has been used for broader resource objectives. Because several general concepts in resource management can be especially important when managing watersheds, they are briefly reviewed first.

Resource Management Concepts

Sound resource management and decision-making begin with good planning, including both a short- and a long-term perspective (sometimes referred to as tactical and strategic planning, respectively), the latter being especially appropriate for forests and related resources. A simple conceptual model for watershed management planning is shown in Fig. 16.1. The elements shown in the three boxes at the left provide much of the foundation and direction for management.

Despite the general proliferation of natural resources information and increasingly sophisticated means of accessing and displaying it, effective management still often requires both updated resource inventories and careful organization of relevant existing information. In watershed management, some key categories of inventory include: watershed boundaries; property boundaries and uses; terrain, geology and soils; climate; hydrology; water quality;

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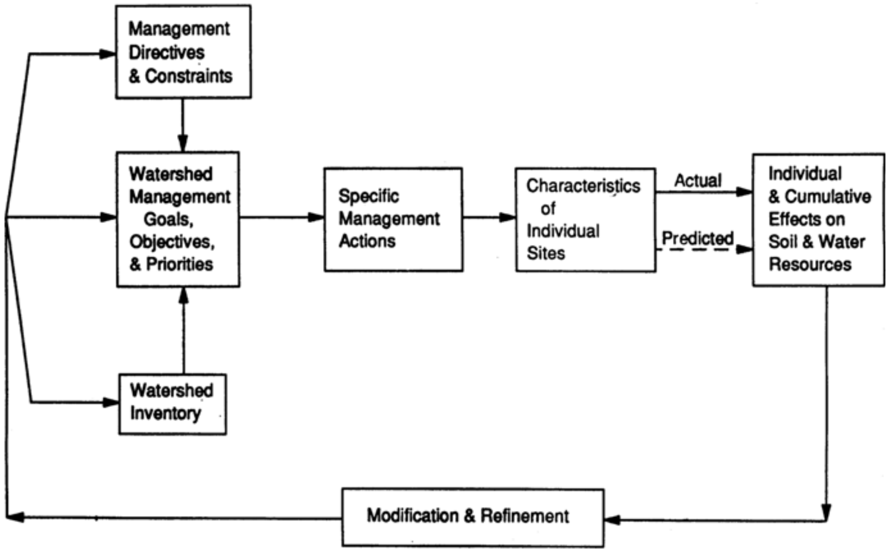

Fig. 16.1 Conceptual model for wildland watershed management planning. Reproduced from Satterlund and Adams 1992, with permission from John Wiley & Sons, Inc

vegetation; construction features; and socio-economic considerations (Satterlund and Adams 1992). The costs of inventory and information organization can be significant, but they should be carefully weighed against benefits of improved decision-making.

Historical knowledge long has been used in the social sciences, and its application to natural resource management has expanded considerably in recent years. In the Pacific Northwest, one of the most enlightening areas of recent study has been the patterns of wildfire. The Douglas-fir forest region of western Oregon and Washington, for example, apparently experienced very large (i.e., tens of thousands of hectares), high-severity fires every 150 years or so (Agee 1990). Such fires are known to have major effects on soil and water resources (e.g., increased erosion and sedimentation), as well as on forest ecology. Understanding these and other important natural influences (floods, droughts, volcanoes, etc.) can help managers make better judgments about the relative effects of human activities on natural resources.

Resource management decisions for both private and public lands are strongly shaped by the basic values of the organization or individuals involved, often expressed through statements of goals or objectives. Laws or policies such as the Oregon Forest Practices Act or the National Forest Management Act provide further direction or limits to management, as does the social or cultural environment. Although the importance of these controlling influences is widely recognized, their detailed and explicit revelation may be a critical early step in effective management planning and decision making.

Decisions about specific management actions usually require information about the specific sites involved, with more detail than typically provided by a general resource or watershed inventory. Effects of actions then can be predicted by formal (models, etc.) or informal (local experience, etc.) means, and a decision made to proceed with or revise plans. Concerns about the cumulative effects of past, present, and future management actions are now receiving much attention, although the means for evaluating such effects remain relatively unrefined. Even where there is considerable confidence that management effects have been accurately predicted, monitoring of results and refinement of actions are additional key steps in management planning (Fig. 16.1).

Finally, as technology increases our ability to both predict and identify environmental effects that result from management practices, we are especially challenged to very carefully interpret the significance of these effects. Both profound and subtle environmental changes occur over short and long time scales even in pristine watersheds. Depending upon the specific resource of interest, management practices can have positive, negative, neutral, or some combination of effects, and a widely variable duration of influence. Because the phrase “management impacts” typically infers only negative effects, use of this terminology when assessing effects may limit creative and scientific (i.e., critical) thinking about natural resources that inherently are much more diverse and complex in their responses to management.

Watersheds as a Basis for Resource Management

The 1990s could be considered the “watershed decade” in that never before had so much attention been given to watersheds as a basis for resource management. In the Pacific Northwest, concerns about such issues as declining wild fish stocks, cumulative effects, and domestic water supplies have often been framed with a watershed perspective. The attention to watersheds paralleled interest in “ecosystem management,” which often itself is cited as requiring a basin or landscape perspective. Indeed, many concepts of watershed and ecosystem management seem to go hand in hand, particularly with respect to aquatic ecosystems, whose structure and function may extend from a high mountain spring to the mouth of an estuary.

While attractive conceptually, however, both watershed and ecosystem management can present formidable challenges in implementation (Adams and Atkinson 1993). In many larger watersheds, varying land use and ownership patterns result in diverse management objectives and constraints. For example, the Oregon Forest Practices Rules require significant riparian protection measures on forest lands (See Chapter 6), whereas adjacent agricultural and other lands generally have had more limited requirements. Even where ownership or administration is consistent, physical and biological conditions may vary greatly, and natural and human influences may extend from beyond the watershed boundary. Examples of the latter include atmospheric deposition

from pollution sources many kilometers away, ocean thermal conditions that reduce anadromous fish numbers that can spawn in fresh water, and national and international needs for wood products and trade that stimulate timber harvesting.

Perhaps the greatest opportunity for using watersheds in resource management is in providing a logical framework or checkpoint for planning efforts. As long as external influences and social dimensions are accounted for, watersheds remain uniquely suited for evaluating and planning management policies and practices, especially when soil and water resources are the focus. Because timber harvesting and related forest practices are of such interest and concern when managing watersheds in which forests are abundant, these will be examined in some detail in the remainder of this chapter. The discussion will emphasize forest practices and knowledge gained in western Oregon, but many of the general principles should be widely applicable.

Timber Harvesting

Timber harvesting can directly alter vegetation cover, soil conditions, and stream channels, which in turn may significantly influence water quantity and quality and related resources. Harvest systems, scheduling, layout, and operations represent the key areas in which management options are likely to be available for controlling the positive and negative effects of timber harvest (Murphy and Adams 2005). Technology and experience in timber harvesting have evolved greatly over the years, and a variety of important developments are highlighted below. These newer developments and their relative environmental performance should be carefully considered when reviewing research literature and other information on watershed effects of timber harvesting that may have occurred decades ago. It is also essential to clearly identify the specific practice in question, because the diverse practices associated with logging (e.g., road construction, felling, yarding, hauling, slash treatment) may individually yield widely different watershed effects in any given location (Adams and Andrus 1991).

Harvest Systems

There are many types of harvest systems and equipment options with which individual timber harvesting operations can be conducted. However, in a given geographical area, choices may be limited by local availability, trained personnel, or cost. Environmental performance among major systems (e.g., ground, cable, aerial) does vary somewhat, but generalizations are not particularly useful because each system can perform well when correctly matched to site conditions and when operations are carefully planned and conducted.

Ground-based harvest systems are most widely available and used, although individual equipment types and combinations vary considerably, especially

given the trend toward increasingly mechanized systems. The most basic ground-based system is the draft animal, which is still in limited use throughout the United States. Unless soils are steep, wet, or weak, horses and other animals can perform well in pulling logs to a central landing location, but their low overall productivity and short-distance yarding capabilities are best suited to small operations with good road access. Note that timber harvest systems and forest roads are inextricably linked together; characteristics and decisions of one can greatly influence the other (see sections below).

Wheeled skidders, crawler tractors, and other tracked vehicles are often used to move (i.e., yard) logs or whole trees to the landing. Increasingly, powered vehicles also are used to fell, limb, and assemble trees or logs for yarding. The array of machines and mechanized logging procedures has become so complex that terminology has been defined for them (Kellogg et al. 1993). With any logging vehicle, there is potential for soil exposure, displacement, or compaction, which may lead to increased runoff and erosion, particularly in sloping terrain. Although some variation in soil effects from different vehicles has been observed (Cafferata 1992), these soil effects can occur with virtually any vehicle and are usually best managed through harvest scheduling, layout, supervision, or post-logging treatments (see sections below).

Cable harvest systems are widely used in areas of steep terrain in the Pacific Northwest. Often considerably more costly than ground-based systems, cable systems encompass a variety of equipment types and combinations. Historically, "highlead" cable systems with limited log lift capabilities were commonly used, in some cases resulting in considerable soil exposure and displacement along cable paths. More recent technical advancements have made "skyline" cable systems the norm, often with sophisticated carriages (Studier 1993) and intermediate supports (Mann 1984) that provide a high degree of log lift and control over soil or stream disturbance. Another trend has been the downsizing of cable equipment, which reduces costs and better matches the timber sizes now being cut (Kellogg 1981). Aerial harvest systems include balloons and helicopters, which also have seen some downsizing and improved cost competitiveness (still generally more costly than cable systems, however), and which offer another option for environmental control (Studier and Neal 1991).

Harvest Scheduling

Scheduling of timber harvest activities is important in both the short and long term. Seasonal conditions such as rain, snow, freezing, and thawing can greatly affect soil trafficability and other operational influences that may yield undesirable soil and water effects, especially when using ground-based systems. Soil disturbance generally is reduced when logging is conducted when soils are relatively dry, or deeply frozen or snow covered. Soil compaction (i.e., increased soil bulk density) from logging vehicles may occur even with dry soils (Cafferata 1992), however, and other management approaches such as harvest layout or

post-harvest treatments (see sections below) may be needed if undesirable watershed effects are expected.

Harvest scheduling over the long term can be a consideration in larger watersheds where multiple operations are expected. For example, harvests may be scheduled to avoid or take advantage of the streamflow increases that can result from reductions in evapotranspiration following logging. Because such flow effects are proportional to the degree of harvest, and decline within a few decades as the new forest canopy develops (Harr 1983), within a watershed the sequence and nature of individual harvests over the years may merit evaluation. Other resource effects of logging can show similar patterns of response followed by a period of recovery (e.g., stream shade and temperature), which can also be considered in harvest scheduling within watersheds. Where there are sufficient data, the integration of multiple temporal and spatial factors to evaluate resource effects is well suited to computer analysis, which increasingly has been used to support harvest planning (Sessions 1992).

Harvest Layout and Operations

Once a general harvest area and system are identified, the specific layout and operational details help bring the plans to life. In and near any harvest area, key control points related to watershed resources should be identified. These include such features as steep slopes, streams, and perennially wet soils. With ground-based harvest systems, the layout and use of a planned skid trail network can be an effective means of controlling traffic patterns and soil impacts (Garland 1993). Most soil compaction occurs within the first few passes of logging machinery, so it is usually preferable to concentrate impacts within a relatively small area of defined trails rather than attempt to disperse vehicle traffic. The longevity of compaction makes planned trail networks especially attractive where intermediate stand entries are expected (i.e., cumulative effects are avoided). Trail layout and associated practices such as line pulling and log winching may add to logging costs, but these usually are not unreasonable and may even be offset by productivity gains from yarding over an efficiently designed trail system (Olsen et al. 1987).

When using cable systems, log suspension and control are greatly affected by harvest layout. Changes in landing location or orientation of the cable path can mean the difference between good suspension or heavy gouging and soil displacement, even on steep slopes. Uphill yarding generally is preferable to a downhill layout, which may concentrate soil exposure and surface runoff along the slope near the landing. Cable yarding layout has been aided in recent years by computer programs that can help define the operating limits of a given system and its most effective application for the local timber and terrain (e.g., Jarmer 1992).

Many watershed effects from logging can be avoided or minimized by harvest layouts that provide an area of little or no disturbance adjacent to streams

(e.g., buffer strip). Appropriate widths and other characteristics of buffers have been the subject of considerable analysis and debate in the Pacific Northwest (Adams 2007; Belt et al. 1992). Design criteria can vary depending upon the specific site conditions and resource concerns, e.g., fish habitat or domestic water supply. As interest in increased protective measures has grown, so too has concern about costs and other operational constraints, which may now stem from not only stream buffers (Olsen et al. 1987), but also modified harvest practices upslope (Kellogg et al. 1991). In addition, the complexity of harvesting and resource interactions demands a thorough analysis of any environmental trade-offs, i.e., determining whether protection measures create new or more serious environmental problems such as buffer blowdown or more roads (Adams et al. 1988).

Harvest systems, scheduling, layout, and other plans are operationally implemented by forest workers. Despite their importance in accomplishing management objectives and avoiding resource problems, field personnel and their knowledge, skills, and abilities sometimes are overlooked during harvest planning. Timber harvesting is physically demanding and dangerous work that can result in relatively high turnover. Practices that protect or enhance watershed resources may be relatively challenging or require new equipment. Training and incentive programs may be desirable to maintain or improve job skills and environmental performance. Supervision and communication among forest workers also can be valuable tools, e.g., even the most well-intentioned worker may be unaware of a specific resource concern or a simple procedural means for avoiding a problem.

Forest Roads

Landslide surveys and other watershed studies in the Pacific Northwest have shown that forest roads sometimes can be key sites for runoff and erosion, particularly in steep terrain (Ice 1985; King and Tennyson 1984; Reid and Dunne 1984). Road construction typically results in exposed, excavated, and compacted soils, as well as new surface drainage features and stream crossings; each may contribute to watershed effects during or some time after construction. However, like timber harvesting, technology and procedures for road construction and use have advanced greatly in the past few decades, and these improvements should be considered when interpreting historical effects relative to expectations for both new and existing forest roads. In particular, careful consideration of road area, location, design, construction, and maintenance likely can avoid most watershed problems (Adams and Andrus 1990).

Road Area and Location

Some roads exist in nearly all forest watersheds, but they may be inadequate for current or projected needs for logging, fire control, recreation, and other

purposes. Both environmental concerns and the high costs of road construction make minimal road construction desirable. When roads are built to support timber harvesting and log hauling, the expected harvest system and hauling routes can be important influences on road planning. Necessary road spacings and the resulting total area in logging roads, for example, are directly related to the maximum practical yarding distance for the logging system (Table 16.1). Newer computer programs for road network design can account for the needs of different logging systems as well as other factors such as terrain, transport routes, road standards, and cost components (Sessions 1992).

Historically, many forest roads were located near stream and river channels because of easy construction along moderate slopes and proximity to mills and other developed areas. Such locations increase the opportunities for sedimentation and other impacts, however, and new construction should favor upland road locations or undisturbed buffer strips between roads and water bodies. Stream crossings generally should be minimized, with right angle approaches to reduce soil disturbance near the stream. In steep terrain, upland road locations still present challenges because considerable soil excavation may be needed to create sufficient road width, and adequate road drainage becomes increasingly important to avoid erosion. Ridgetop roads can reduce excavation and drainage needs, but some side slope roads still will be necessary to access ridges and other areas.

Preliminary map and field surveys are essential for good road location. Topographic maps, aerial photos, soil surveys, geographic information systems, and other tools can be very useful in establishing general routes. Field reconnaissance invariably reveals other small-scale features (wet spots, rock outcrops, etc.) that modify road alignment. Additional adjustments may be necessary during the construction phase if excavation uncovers unfavorable localized soil or rock conditions.

Road Design

At one time, forest road construction consisted primarily of a bulldozer operator simply blading off the surface soil and compacting the underlying material to create a relatively hard and level track for vehicles. A few roads, particularly in gentle terrain, are still constructed this way, but forest road design generally has become a much more sophisticated process that may involve several steps

Table 16.1 General relations between timber harvesting systems, maximum yarding distance, and percent area in roads (compiled from various sources for Pacific Northwest conditions)

Harvest system	Maximum yarding distance (m)	Area in roads (%)
Tractor/skidder	450	4–15
Highlead/short skyline	450	3–10
Long/multispan skyline	1500	2–4
Helicopter	2300	1–3

and equipment types. In steep terrain, for example, slope failures can be markedly reduced through the use of a full-bench road design combined with trucking of the excavated material to a stable location (Sessions et al. 1987). Ridgetop roads provide similar benefits, but gradeability and surfacing of the steep roads used to access ridges become additional important design features (Anderson et al. 1987). In general, gravel surfacing reduces sediment losses from roads, although careful surfacing prescriptions (e.g., rock specifications) and subgrade preparation are needed to manage costs and enhance durability. Wet or weak soils, for example, may require the use of synthetic fabrics or other subgrade supplements to enhance surface life and trafficability.

Perhaps the most universally critical aspect of road design with respect to watershed concerns is the drainage system. Water should move efficiently from the road surface to stable areas where it will behave as if the road had not been there; i.e., it will infiltrate the soil. Road surfaces usually are designed with a crown, inslope, or outslope for immediate drainage, and where the road is cut into a slope, an inside ditch often is needed to collect and move water (Garland 1983). On long grades, ditches are supplemented with relief culverts or rolling dips to avoid gully formation. Spacing of ditch-relief culverts or road dips generally should decrease as the road grade or soil erodibility increases. A survey of ditch-relief culverts in the Oregon Coast Range, for example, showed that erosion both in ditches and at culvert outlets increased with long culvert spacings (Piehl et al. 1988a).

Design of stream crossings is another very important consideration, because these are sites of direct interaction with water resources. Several general design options usually are available, including fords, culverts, and bridges, in order of typically increasing cost. For smaller streams, simple fords are a relatively economical option that also may have low maintenance requirements (Warhol and Pyles 1989). Because vehicles drive directly through the stream, however, expected traffic frequency may be important where water quality is a concern. Culverts are the most commonly used stream crossing in the Pacific Northwest, although installation design varies widely. For larger streams and rivers, bridges may be the only viable option. Some of the key design considerations for stream crossings include local hydrology and peak flow events, fish migration, maintenance, management objectives, economics, and legal requirements (Pyles et al. 1989).

Because some of the most serious erosion problems at stream crossings occur during unusually large storms, state forest practice laws in the Pacific Northwest generally require that crossings be designed to withstand a 50-year frequency or larger flow. Although clear in intent, such directives have had variable implementation because data and methods for developing local estimates of peak flows often have been lacking. A survey of culverts in the central Oregon Coast Range, for example, showed over 40% would be unable to pass a 25 year peak flow without ponding above the top of the pipe inlet (Piehl et al. 1988b). Methods for predicting peak flows for stream crossing design have improved, however, including the refinement of predictive tools for areas of

similar climate and other unifying hydrologic characteristics (Adams et al. 1986; Andrus et al. 1989).

Road Construction and Maintenance

Soils exposed during road construction are especially susceptible to erosion for a year or two following excavation, after which revegetation and other stabilization normally reduce erosion hazards. Construction timing relative to wet weather can thus be important, as can the use of plant seedings and physical barriers along road cut and fill slopes (Burroughs and King 1989). In steep terrain, control of road widths and excavated materials can be enhanced by the use of hydraulic excavators, which have become more cost-competitive and widely used in the Pacific Northwest (Balcom 1988).

The function of road drainage systems and other key construction features can only be insured through both routine and emergency maintenance procedures (Adams 1997). Surface grading, culvert and ditch cleaning, and supplemental gravel applications are common needs, especially as traffic levels increase or wet weather promotes rutting, slumping of cut banks, etc. Proximity to streams may be another important criterion for prioritizing road maintenance operations. Traffic control during wet weather can reduce sediment losses from roads, but even during dry weather overall sediment losses from forest roads can increase with heavier traffic loads (Bilby et al. 1989).

Permanent road closure may be a viable option where access no longer is a priority and where maintenance costs or risks of erosion are high. Although hydraulic excavators and other advanced equipment make possible the complete deconstruction of roads (i.e., fill material returned to approximate the original slope), such costly measures probably are unnecessary for the protection of watershed resources, as long as drainage is adequately provided for during closure (e.g., construction of water bars). Where older roads are still needed and potential watershed impacts remain a concern, upgrading of road standards (e.g., type or thickness of surfacing, culvert spacing or sizing, maintenance frequency) may be desirable.

Other Forest Practices

Forest management normally involves considerably more than just road construction and timber harvesting. Slash treatment, site preparation, reforestation, and stand treatments are common practices often stimulated by legal or economic concerns. In addition, insect and disease problems, wildfire, ice and wind damage, and other considerations can prompt some unique management responses. Because these practices may yield their own diverse watershed effects, management and policy decisions should proceed from a clear understanding of

specific cause-and-effect relations among the many individual practices and resources that may be encountered.

Slash Treatment and Site Preparation

Slash that is left after logging may be treated in a variety of ways for one or more purposes, including wildfire hazard reduction and preparing the site for successful reforestation. Improved planting ease, control of competing vegetation, increased nutrient availability, and insect and disease control may be primary objectives. Because of the historical importance of fire in Pacific Northwest forests, prescribed burning treatments have been widely applied in the region with generally very positive results for reforestation, although questions are likely to persist about long-term effects and site-specific prescriptions (Walstad et al. 1990).

Both prescribed and natural fire, for example, may produce some undesirable effects on watershed resources, at least in the short term until revegetation occurs. If fires are of sufficient severity, soils and stream channels may be exposed to the erosive forces of water, wind, and gravity (Ice et al. 2004). Changes in physical properties that increase surface runoff (e.g., increased water repellency) may also occur (McNabb and Swanson 1990). Burning mineralizes some of the nutrients contained in slash, which may then leach from soils into water bodies. The most significant changes in water quantity and quality that have been noted in the region have occurred following wildfires or very hot slash burns; generally negligible changes are expected with low intensity prescribed burning (Beschta 1990). Control of burn intensity thus appears to be a primary means of avoiding undesirable impacts, although this approach needs to be weighed with such trade-offs as air quality (i.e., less intense burns produce more smoke) and reforestation benefits.

Slash treatment and site preparation often involve the use of heavy equipment that may produce its own effects on watershed resources. Piling of slash with crawler tractors, for example, may result in significant soil exposure and compaction. Site preparation with tractor-mounted brush rakes may produce similar effects, although compaction may primarily occur in the subsoil while the surface soil is somewhat loosened. These soil effects from post-logging treatments also may negate efforts made during logging (e.g., use of designated skid trails) to minimize compaction. Where soil compaction is an unavoidable result of logging or other practices, it may be alleviated through the use of soil tillage treatments (Cafferata 1992). The effectiveness of tillage implements varies widely, however, and other measures such as the construction of water bars may still be needed to protect watershed resources.

Herbicides are sometimes used as a site preparation measure to eliminate vegetation that would compete with desired species for moisture, light, nutrients, or space. Most herbicides act specifically to disrupt plant growth mechanisms and are of relatively low toxicity to humans and animals. They also are less likely than

broadcast burning or mechanical methods to increase erosion (Table 16.2). Still, many people are concerned about such manufactured chemicals entering water supplies, in part due to the detection of more toxic contaminants found in earlier formulations of some herbicides (Walstad and Dost 1984). Toxicity is only part of what constitutes a chemical hazard, however. Equally important are the likelihood and degree of exposure, which are governed by the application methods and how the chemical interacts with the local environment (Norris et al. 1991). Contamination of water supplies often can be avoided by ensuring that herbicides are applied at minimum effective concentrations well away from water bodies. However, in situations where the risks from chemical use are determined to be high, alternative practices may be most appropriate.

Reforestation, Stand Management and Other Considerations

Reforestation after logging is a legal requirement in the Pacific Northwest. In some cases, the new forest may differ enough from the original forest in species or structure to affect water resources. For example, past logging practices in some locations apparently have encouraged the regrowth of riparian alder stands, which may affect water quantity (Hicks et al. 1991) and quality (Taylor and Adams 1986). Although land use laws now limit widespread changes in forest cover, some conversions to agriculture, residential, or industrial uses are possible, and these new uses may uniquely affect local watershed resources. Afforestation of agricultural or other open lands also may occur, and if a large enough part of the watershed is treated this way, streamflows may be reduced

Table 16.2 Total soil movement to hillslope erosion collection boxes 45 months after various site preparation and conifer release treatments in the Oregon Coast Range (Stednick, J.D, P.W. Adams, and W.R. Stack 1991, unpublished report to USDA Forest Service, Pacific Northwest Research Station, Portland, OR)

	Cumulative soil movement (kg)
SITE PREPARATION TREATMENTS	
Control – no site preparation treatment	3.8
Broadcast Burn – late summer, early fall	12.7
Aerial Spray – glyphosate, early fall	7.5
Manual Scalp – 1m radius, before planting	4.1
Spray and Burn – aerial picloram, June; fall burn	3.7
Slash and Burn – manual, June; burn late summer/early fall	9.3
CONIFER RELEASE TREATMENTS	
Control - no conifer release treatment	2.4
Manual Cut 1x – 1m radius, once, late spring	0.7
Manual Cut 2x – 1m radius, twice, late spring	1.5
Manual Cut 3x – 1m radius, three times, late spring	1.1
Aerial Spray – glyphosphate, early fall	2.1

because evapotranspiration loss from forest cover is higher than from most other types of vegetation.

Forest plantation and stand treatments may include brush release, fertilization, and insecticide and rodenticide applications. Brush release is usually performed with herbicides, but manual treatments are sometimes used. When carefully performed, both approaches generally have little or no effect on soil and water resources (Table 16.2), primarily because soil disturbance is avoided or of very limited areal extent. Guidelines for fertilizer, insecticide, and rodenticide applications generally follow those of herbicides, i.e., minimum effective amounts away from water bodies and runoff areas (e.g., ephemeral channels, road ditches). Insecticides and rodenticides may require a greater level of care, however, due to generally higher toxicities than herbicides and fertilizers.

In addition to silvicultural practices, other activities and influences on or near forest lands may be important to watershed resources. Livestock grazing may be a concern, particularly if animals are allowed to intensively graze riparian areas or to freely access streams for watering. Although most experience in grazing and watershed management in the Pacific Northwest has been from drier inland areas, the basic principles should be widely applicable: Carefully manage the level and season of grazing to maintain adequate plant cover and streambank and channel structure (Clary and Webster 1989). Concentrations of large, grazing wildlife (elk, deer, etc.) also may affect watershed resources, but management may be more difficult. Beaver can profoundly affect stream channels and water quality, in some cases causing problems (e.g., domestic water supplies) and in others providing apparent benefits (Leidholdt-Bruner et al. 1992).

Finally, although forest recreation is often dispersed, water bodies attract people and can create areas of concentrated use that may lead to erosion, biological contamination, or other problems (Clark et al. 1985; Cole 1989). In addition, use of 4-wheel drive vehicles, mountain bikes, or horses may lead to soil disturbance and erosion, particularly in wet or sloping ground. Controlling access to or intensity of use of riparian and other sensitive areas can be challenging, but is among the most effective approaches to limiting watershed impacts from recreation. Direct education and communication with recreation users can play a key role in raising awareness and cooperation in controlling local watershed impacts.

Conclusions

Watershed management is a growing, yet relatively complex and challenging approach to managing natural resources on forest lands. Although it lacks a fully comprehensive research base and widely accepted evaluation procedures, we appear to have both sufficient knowledge and experience to use improved practices and decisions to avoid most problems when managing forest resources in a watershed context. Education tapping this knowledge and experience can

play a particularly important role in promoting positive practices and decisions, especially in light of prevailing watershed misconceptions, a lack of focus on cause-and-effect relations among watershed practices and resources, and the widely variable backgrounds of those involved with management and decision making in watersheds (Adams and Cleaves 1993). As we have learned throughout the realm of natural resource management, it is not only what we do, but how we choose to do it that makes the difference between positive or negative results.

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